Geological Survey
of Canada

Current Research
2000-E11

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2000

Natural Resources Canada | Ressources naturelles Canada

Canada

100-06735/

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Catalogue No. M44-2000/E11E-IN
ISBN 0-660-18217-3

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Electrical resistivity stability characteristics of water used to saturate rocks from Giant and Con mines, Yellowknife, Northwest Territories[1]

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Connell, S., Katsube, T.J., and Scromeda, N., 2000: Electrical resistivity stability characteristics of water used to saturate rocks from Giant and Con mines, Yellowknife, Northwest Territories; Geological Survey of Canada, Current Research 2000-E11; 6 p. (online; http://www.nrcan.gc.ca/gsc/bookstore)

Abstract: Differences in petrophysical properties (e.g. porosity and electrical resistivity) were noted between similar rock types from Giant and Con mines in the Yellowknife mining district (Northwest Territories). For example, the time required for resistivity of the rock samples to stabilize after pore-water saturation was considerably longer for Giant mine samples compared to Con mine samples. An exploratory study was initiated to find an explanation for these differences. This involved monitoring the resistivity of water used to immerse samples from the two mines, over a period of 340 hours, after vacuum saturation.

Results indicate that considerable differences existed between the resistivity-time curves of the water in which the samples (sericite schist and basalt) from the mines were immersed. The resistivity of the water containing Giant mine samples was consistently higher and required considerably longer time to stabilize, compared to the Con mine samples. These differences are consistent with the differences in the sample porosity and electrical resistivity.

Résumé : On a relevé des différences dans les propriétés pétrophysiques (p. ex. porosité et résistivité électrique) entre des types de roches semblables provenant des mines Giant et Con dans le district minier de Yellowknife (Territoires du Nord-Ouest). À titre d'exemple, le temps nécessaire pour que la résistivité d'échantillons de roches se stabilise après leur saturation en eau interstitielle s'est révélé considérablement plus long pour les échantillons de la mine Giant que pour les échantillons de la mine Con. Pour expliquer ces différences, on a entrepris une étude exploratoire qui consistait à surveiller la résistivité de l'eau utilisée pour immerger des échantillons provenant des deux mines pendant 340 heures, et ce, après leur saturation sous vide.

Les résultats obtenus indiquent des différences marquées dans les courbes de la résistivité en fonction du temps de l'eau d'immersion des échantillons (séricitoschiste et basalte). La résistivité de l'eau contenant des échantillons provenant de la mine Giant était uniformément plus élevée et prenait beaucoup plus de temps à se stabiliser que celle contenant des échantillons de la mine Con. Ces différences concordent avec celles relevées sur la porosité et la résistivité électrique des échantillons.

[1] Contribution to the 1999-2003 Yellowknife, Canada-Northwest Territories Exploration Science and Technology (EXTECH III) Initiative

INTRODUCTION

The electrical resistivity change with time of deionized water in which rocks from the Giant and Con mines in Yellowknife mining district, Northwest Territories, were immersed has been measured over a period of 340 hours. The purpose of the study was to determine whether the differences in petrophysical characteristics, previously observed between rocks from the two mines (Scromeda et al., 2000), were associated with the presence of soluble mineral phases in the rocks.

Petrophysical measurements, including electrical resistivity and porosity, were previously carried out on ten representative rock samples from the Giant and Con mines (Scromeda et al., 2000). A number of differences in the petrophysical characteristics were identified between rocks of similar types from these mines, e.g. differences in the porosity and irreducible water saturation values. Irreducible water saturation is a parameter related to the amount of water remaining in a rock after vacuum drying at room temperature. The error ranges of the electrical resistivities for the Con mine samples were considerably higher than those from the Giant mine. According to standard procedures applied in our measurements, electrical resistivities are measured 24 and 48 hours after vacuum saturation with deionized water (180 000 Ω·m). The resistivity values usually stabilize 12 hours after vacuum saturation. Measurements are normally taken at two different times, 24 and 48 hours, to ensure stability. Resistivity differences between the measurements at these two times, are normally smaller than ±20% and are considered to represent measurement error. The large differences for the Con mine samples are greater than the expected error and indicate a possible lack of pore-water stability for samples from that mine, which is highly unusual.

Two representative rock samples, a relatively fresh mafic volcanic and an altered quartz sericite schist, were selected from each of the mines (four samples in total) for this study. Subsequent to vacuum saturation, each sample was placed in a beaker containing deionized water, and the resistivity of the water in each beaker was measured over a period of 14 days. The purpose of this paper is to document the results of this study and create a database for future analysis that could enable a better understanding of the causes of the differences seen between the petrophysical characteristics of samples from the two mines.

Table 1. Rock descriptions and locations of samples collected from the Con and Giant mines (Yellowknife, Northwest Territories), and their visually estimated sulphide content.

Mine	Sample number	Stope sampled	Lithology	Sulphide content	W_s (g)
Con	**MYC-1**	**3148R**	**Sericite schist**	**≤2%**	17.4
	MYC-2	3148R	Chlorite-sericite schist	2%	
	MYC-6	**3148R**	**Basalt**	**trace - 1%**	20.1
	MYC-7	3196R	Chlorite schist	trace	
	MYC-11	3322AY	Ore	2 - 5%	
Giant					
	MYG-8	370	Chlorite schist	trace	
	MYG-9	370	Ore	≥10%	
	MYG-11	370	Sericite schist	5 - 7 %	
	MYG-13	**370**	**Sericite schist**	**2 - 3%**	13.3
	MYG-1	**Surface**	**Basalt**	**trace**	17.5

Note: Sample number in bold indicates those used in this study
W_s =Weight of sample used in this study prior to saturation

METHOD OF INVESTIGATION

Samples and sample preparation

The four samples used in this study were chosen from the suite of ten samples which had previously been collected from the Giant and Con mines for petrophysical studies (Scromeda et al., 2000). Irregular-shaped chip samples of similar size and weight (13.3–20.1g, *see* Table 1) were taken from the original hand samples, and prepared for this study. For the most part, 2–3 sides of the irregular-shaped samples had been cut with a rock saw while the others are rough. While efforts were made to maintain similar size and shape, there are slight variations.

Petrophysical data

Information on sample site location and lithology is listed in Table 1. The petrophysical data for the samples used in this study, including effective porosity and electrical resistivity, are listed in Table 2. The procedures used to obtain these data can be found elsewhere (Scromeda et al., 2000).

Method of investigation

First, each sample was placed in a beaker and vacuum saturated in 400 mL of deionized water (180 000 Ω·m) for 15 minutes before the first reading was taken (Katsube et al., 1991). Secondly, the conductivity of the water in each of the beakers was measured at regular intervals, using a YSI Model 32 Conductance Meter, over a period of 14 days. A reading was taken immediately following saturation and then every hour for the first 8 hours. Readings were taken less frequently as the water equilibrated. The conductivity values obtained were then multiplied by a cell constant of 0.1072/cm with an error range of 0.55%, and resulting values converted into electrical resistivity (Ω·m).

Deionized water

The deionized water used in this study is type 1 reagent grade water (180 000 Ω·m) that has a significant reduction in organics and pyrogens. The water is purified by filtration through four deionizing cartridges (Katsube et al., 1992). This process is an improvement over water purification by distillation which produces water in the range of 30 000–80 000 Ω·m with ions, organics, and pyrogens still in solution.

EXPERIMENTAL RESULTS

The resistivities of the waters in which the rocks were immersed are listed in Tables 3a and 3b and the curves, representing the resistivities as a function of time, for the four samples are shown in Figure 1. Whereas the shape of the four

Table 2. Petrophysical data for rock samples from Con and Giant mines, Yellowknife, Northwest Territories (Scromeda et al., 2000).

Sample	δ_B (g/mL)	S_w (%)	ϕ_E (%)	Mean ρ_r (10^3 Ω·m) α	ε(%)	β	ε(%)	γ	ε(%)	Anisotropy (λ)
Con mine										
MYC-1	2.99	17.4	1.16	5.90 ± 2.4	± 41	0.98 ± 0.32	± 32	0.60 ± 0.16	± 27	10:1
MYC-2A	3.02	25.0	0.80	1.56 ± 0.36	± 23	3.61 ± 0.9	± 2	5.38 ± 0.23	± 4	3:1
MYC-2B				7.51 ± 0.74	± 9	4.45 ± 0.98	± 18	1.96 ± 0.32	± 16	4:1
MYC-6	3.02	47.5	0.40	3.71 ± 1.48	± 40	7.20 ± 2.54	± 35	4.47 ± 1.62	± 36	2:1
MYC-7	2.92	23.0	0.54	13.22 ± 1.68	± 13	4.45 ± 0.91	± 20	1.94 ± 0.37	± 19	7:1
MYC-11	3.12	51.0	0.56	3.43 ± 0.98	± 28	2.42 ± 0.82	± 34	2.13 ± 0.52	± 24	1.6:1
Giant mine										
MYQ-1	3.13	24.0	0.42	23.77 ± 1.82	± 7	12.50 ± 1.16	± 9	7.00 ± 0.76	± 11	3:1
MYG-8	2.86	3.8	3.03	13.52 ± 0.39	± 3	4.24 ± 0.05	± 1	2.07 ± 0.02	± 1	6:1
MYG-9	3.12	10.5	2.55	1.69 ± 0.09	± 5	0.037 ± 0.003	± 8	0.13 ± 0.0	± 0	46:1
MYG-11A	3.04	9.4	1.97	5.08 ± 0.09	± 2	0.36 ± 0.0	± 0	0.62 ± 0.01	± 2	14:1
MYG-11B	2.91	5.8	2.86	1.62 ± 0.05	± 3	2.97 ± 0.05	± 2	6.61 ± 0.31	± 5	4:1
MYG-13	3.05	27.8	1.46	2.40 ± 0.26	± 11	1.25 ± 0.15	± 12	0.58 ± 0.02	± 3	4:1

Note: =Sample number in bold indicates those used in this study
δ_B=Bulk density (g/mL)
ϕ_E=Effective porosity (%)
S_w= Irreducible water saturation
ρ_r=Mean bulk electrical resistivity for measurements made after 24 and 48 hours saturation (Scromeda et al., 2000)
α, β, γ=Three directions of the electrical measurements
ε=Percentage difference calculated between the two measurements (24 and 48 hour)

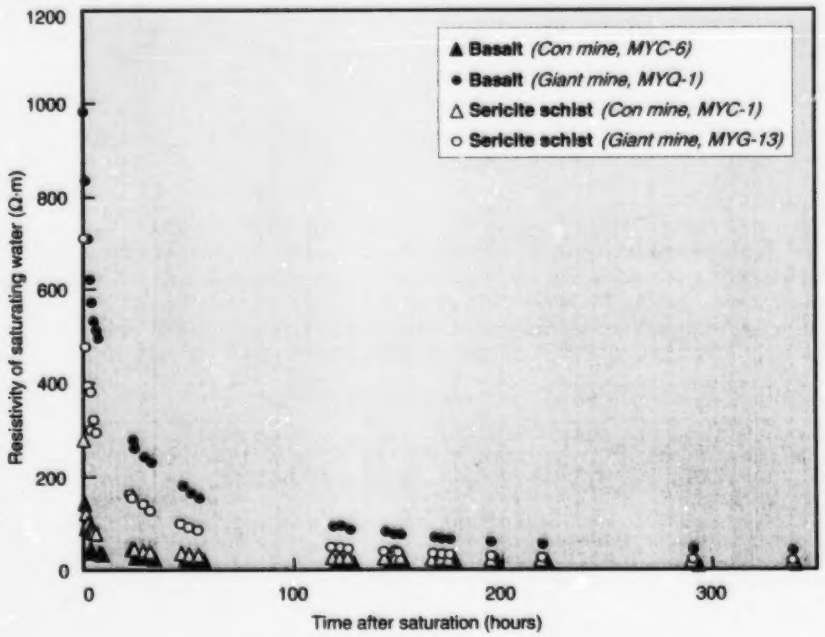

Figure 1. *Diagram showing the electrical resistivity of the water in which the rocks were immersed as a function of time for each of the four samples (MYC-6, MYC-1, MYQ-1, and MYG-13). The resistivity of the deionized water prior to saturation was 180 000 Ω·m.*

curves are very similar, the two for Giant mine (MYQ-1 and MYG-13) consistently display higher resistivities than those for the Con mine (MYC-1 and MYC-6). Another noticeable difference is that the two Giant mine samples take a considerably longer time to equilibrate (approximately 150 hours) compared to those from the Con mine (approximately 30 hours).

The resistivities of the immersing waters are displayed plotted against log time in Figure 2. The data for the two Con mine samples are replotted to better display the changes in resistivity with time in Figure 3. Three of these curves (MYQ-1, MYG-13, and MYC-1) suggest a three-stage system.

Table 3. Results of resistivity measurements of the water used to saturate the rock samples.

Hours saturated	Resistivity (Ω•m)			
	Basalt		Sericite schist	
	MYC-6	MYQ-1	MYC-1	MYG-13
0	143.96	985.04	278.46	717.01
1	92.18	835.13	123.55	483.33
2	45.5	711.55	101.18	398.65
3	41.46	624.39	88.59	385.47
4	38.39	572.99	87.76	303.86
5	38.23	536.11	83.51	327.31
6	37.77	513.68	79.05	300.91
7	37.46	495.93		
8	35.2			
22				165.69
23			44.63	159.19
23.5		278.46		
24	28.18	262.03	43.8	
25	30.29			
28.5			40.38	142.85
29		243.56		
30	27.6			
31.5			39.19	132.32
32		231.47		
33	26.65			
46				104.23
46.5			36.02	
47		180.78		
48	23.56			
50				95.09
50.5			32.62	
51		165.1		
52	21.64			
54				90.65
54.5			32.39	
55		154.7		
56	21.74			
118				52.91
118.5			27.04	
119		93.1		
120	17.73			
122			26.88	53.55
122.5		93.56		
123.5	17.9			
126			26.65	49.67
127		87.26		
128	17.63			

Hours saturated	Resistivity (Ω•m)			
	Basalt		Sericite schist	
	MYC-6	MYQ-1	MYC-1	MYG-13
143				45.95
143.5			25.77	
144		80.77		
145	17.18			
148		76.65		45.73
148.5			25.91	
149	16.81			
150				44
150.5			25.63	
151		76.15		
152	17.21			
166.5			24.68	41.28
167.5		69.98		
169	16.42			
170			24.29	
170.5				39.19
171		66.97		
172.5	15.47			
174			23.5	
174.5				38.87
175		66.97		
176.5	15.5			
194		61.05	22.64	
194.5				35.6
196.5	14.97			
218			21.15	
218.5				31.3
219		54.05		
220.5	13.84			
290			19.15	
290.5				27.93
291		44.42		
292.5	12.76			
338			18.04	
338.5				24.42
339		40.56		
340	12.23			

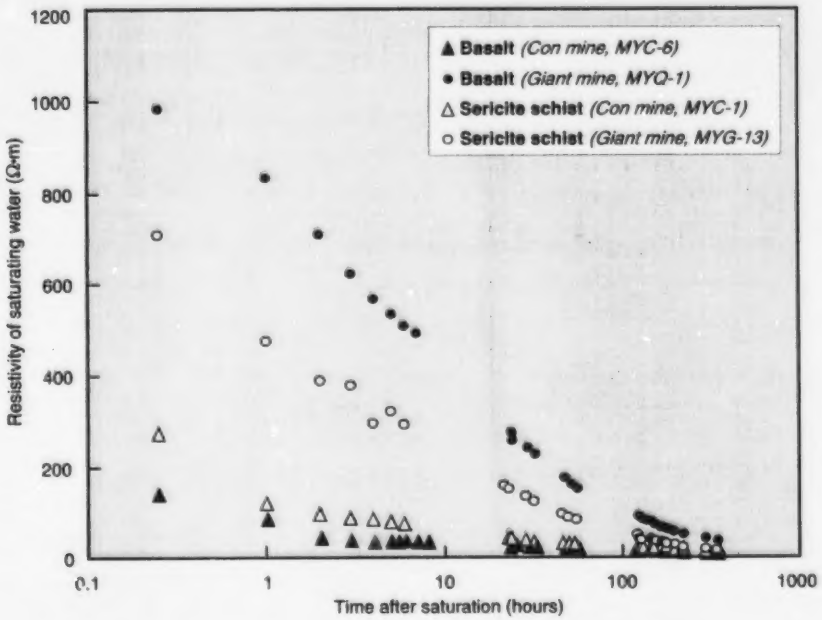

Figure 2.

Semi-log presentation of the resistivity of the water in which the rocks were immersed as a function of time (repetition of Fig. 1) for each of the four samples (MYC-6, MYC-1, MYQ-1, and MYG-13).

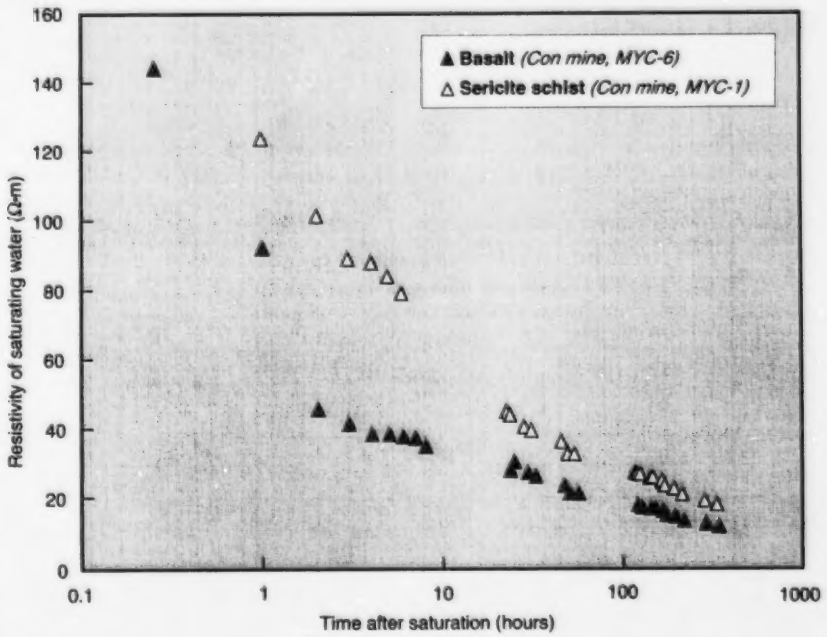

Figure 3.

Semi-log presentation of the resistivity of the water in which the rocks were immersed as a function of time for the two samples from Con mine (MYC-1 and MYC-6).

DISCUSSION AND CONCLUSIONS

The petrophysical property differences between samples from the two mines are very distinct (Table 2). For example, the effective porosities for Con mine and Giant mine samples are 0.40–1.16 % and 2.86–3.13 %, respectively. The irreducible water saturation (S_{ir}) values for samples from the same two mines are 17.4–47.5 % and 3.8–24.0 %, respectively. The S_{ir} values represent the amount of water in the adsorbed water layers (on pore surfaces) after the free water in the pores has been evacuated under vacuum at room temperature (Katsube and Scromeda, 1991; Scromeda and Katsube, 1993). The error ranges of the electrical resistivities were ±2–40% with an average of ±23.4 for the Con mine samples and ±2–12% with an average of ±4.7 for the Giant mine samples.

The curves representing the saturating water resistivity as a function of time shown in Figure 1 and 2, for samples from the two mines, show considerable differences, with the two from the Giant mine (MYQ-1 and MYG-13) consistently displaying higher resistivity values than those from the Con mine (MYC-1 and MYC-6). Since there is some difference in weight of the sericite schist samples — 13.3 g for MYG-13 and 17.4 g for MYC-1, it is likely that this has some effect on the results; however, sample MYC-1 is larger than sample MYG-13 by a factor of 1.3, whereas the saturating water resistivities of the former are about a factor of 3–4 times smaller than the latter (*see* Fig. 2, 0.1–10 hours). These trends suggest that the difference in sample location (Con or Giant mine) overrides data variation due to that of the sample size. Although the resistivity of the original deionized water was 180 000 Ω·m, the final resistivity values after the 340 hour immersion of the rock samples were 1–3 Ω·m for the Con mine samples and 31-47 Ω·m for the Giant mine samples. That is a range of 0.001–0.02% of the original resistivity values. For convenience, in this study we consider stability as being the point at which the pore-water resistivity has reached five times that of the final value, therefore, stability has been reached after 60–90 hours for the Con mine samples and after 130–210 hours for the Giant mine samples.

SUGGESTIONS FOR FOLLOW-UP STUDIES

C. Gregoire (GSC Ottawa):

As a means of gaining more information on the rocks studied, the authors could analyze the waters for trace-metal content to pinpoint the source of conductivity changes and also study the mineralogy on the surface of the rocks as immersion time increases. Possibly, some clues could be uncovered which will help in interpretation.

R.G. Garrett (GSC Ottawa):

The authors should duplicate the work to determine true measurement error. It is suggested that the anions Cl^-, Fe^-, SO_4^{-2}, I^-, Br^- etc. be determined by Dionex ion chromotography, as well as Na, K, Ca, Mg, in the immersion water at the close of measurements. Also determine if the role of fracturing, i.e. surface exposure, might be affecting the resistivity. Larger pore surface area and an abundance of leaching grains, would lead to lower resistivities. One possibility is that minerals such as halite, NaCl, that may have been involved in the ore forming process (hydrothermal solutions) are being leached out (*see* Kesler et al.,1973).

J.A. Kerswill (GSC Ottawa):

It is most intriguing that there are very significant differences between the basalt samples from the two mines. More similar petrophysical values might have been expected for these unaltered rocks. It is also intriguing that the quartz sericite schist from Con mine displays higher conductivity (lower resistivity) of the immersing water than does the unaltered basalt, whereas the quartz sericite schist from Giant mine displays lower conductivity (higher resistivities) than the unaltered basalt. These unexpected differences require additional testing to provide an explanation.

ACKNOWLEDGMENTS

The authors express their sincere appreciation for the critical review of this paper and for the very useful suggestions by C. Gregoire (GSC Ottawa), R. Garrett (GSC Ottawa), J. Kerswill (GSC Ottawa), and C. Jefferson (GSC Ottawa). This work has been supported by the EXTECH-III (EXploration and TECHnology) Project which was initiated in 1999 in the Yellowknife mining district, Northwest Territories.

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Geological Survey of Canada Project 870057